SOLWEIG – A climate design tool

User manual for version 2014a

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Introduction

SOLWEIG is a computer software model which can be used to estimate spatial variations of 3D radiation fluxes and mean radiant temperature (T_{mrt}) in complex urban settings. This document describes the computer software and the graphical user-friendly interface that has been developed for the SOLWEIG model. For detailed description of the model, see Lindberg et al. (2008) and Lindberg & Grimmond (2011). SOLWEIG is written in MATLAB programming language. This involves a certain number of advantages for the aim of this model, as matrices processing are required continuously, a requirement that MATLAB covers perfectly. Therefore better, fast and efficient results are obtained. The Graphical user interface makes use of a runtime engine called the MCR (MATLAB Compiler Runtime), which makes it possible to run MATLAB application outside the MATLAB environment. The MCR is deployed royalty-free.

This document will help you to install and run the SOLWEIG model using the Graphical user interface. It also includes handy tips and recommendation which could be used in order to optimize the model.

Changes from previous versions

Version	Changes from previous version
2014a	– The model is now able to run at any time interval – A new format of the input met. data is introduced – The time stamp is now 'fixed' i.e., 1400 in an hourly dataset represent the hour before.
2013a	A new GUI is introduced as well as options to load gridded vegetation DSMs.
2.3	A new scheme for reflection concerning the shortwave fluxes is included taking into account sunlit and shaded walls
2.2	Some major (and minor) bugs have been fixed such as: – A major bug regarding the scale of trees and bushes is resolved
2.1	Some major (and minor) bugs have been fixed such as: – Small changes in the equations for shortwave radiation. The reflected part is now weighted using a fraction of shadow component instead of sun altitude angles – An error in outgoing shortwave radiation equation have been fixed – The generation of bushes in the vegetation DEM process is improved
2.0	A new vegetation scheme is now included. The interface also has a wizard for generating vegetation data to be included in the calculations. The new vegetation scheme is again slowing down the calculation but the computation time is still acceptable.
1.1	Longwave and shortwave radiation fluxes from the four cardinal points is now separated based on anisotropical Sky View Factor (SVF) images. Ground View Factors is introduced which is a parameter that is estimated based on what an instrument measuring L_{up} actually is seeing based on its height above ground and shadow patterns. In order to make accurate estimations of GVF, locations of building walls need to be known. Walls can be found automatically be the SOLWEIG-model. However, if the User wants to have more control over what are buildings and not, the User should use the marking tool included in the 'Create/Edit Vegetation DEM'. A very simple approach taken from Offerle et al. (2003) is used to estimate nocturnal L_{down}. Therefore T_{mrt} could also be estimated during night in version 1.1.

Migration from 32-bit to 64-bit computer environments

The SOLWEIG interface, as from April 2012, is now running in 64-bit computer environments. This is mainly because of the increased memory capabilities which make it possible to work with even larger model domains than before. Some users might run into problems using the new 64-bit version. Solutions of some of these issues are found in this guide. Please read this manual through before contacting the Urban Climate Group with any further questions. A 32-bit version can be available upon request.

Installation

This section gives you information on how to install the SOLWEIG graphical user-friendly Interface on a regular PC.

System requirements

The Interface runs under WINDOWS NT/2000/XP/Vista/7 64-bit platforms.

Other applications needed before installing the software

There is one additional application that has to be installed on the PC before been able to run SOLWEIG:

- Install the MCR (MATLAB Compiler Runtime 8.2). This can be downloaded from: http://www.mathworks.se/products/compiler/mcr/. If you are using earlier versions of SOLWEIG, you should keep the corresponding MCR installed on your computer. Earlier MCRs could be found at Urban Climate Group webpage[1].

Installing the Interface

Download the executable installation file (SOLWEIG Setup.exe) of the Interface from the Urban Climate Group[1] webpage and follow the installation procedure as shown below (Figure 1-6). The current installation also comes with a sub-version of the SOLWEIG-model called SOLWIEG1D. This application can be used together with hemispherical photographs and can be used to calculate SVF, T_{mrt}, PET and UTCI as well as display sun diagrams.

[1] http://www.gvc.gu.se/english/research/climate/urban-climate/

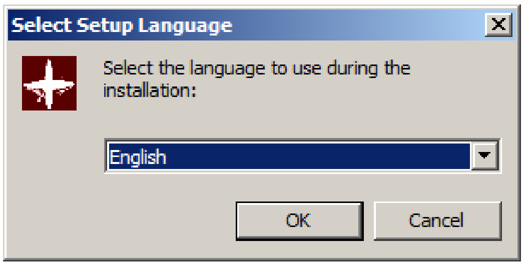

Figure 1. Select setup language.

Figure 2. SOLWEIG setup welcome window.

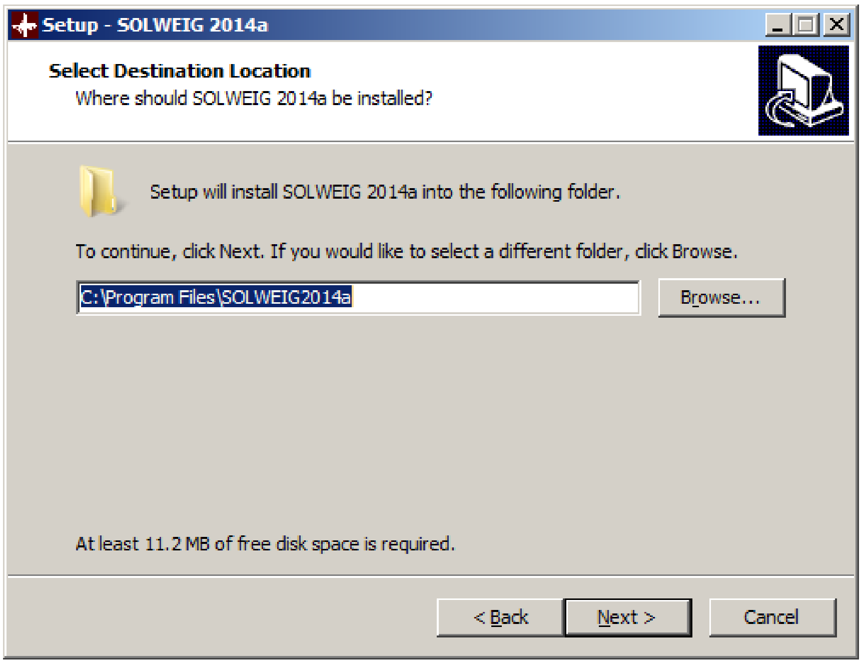

Figure 3. Select destination location.

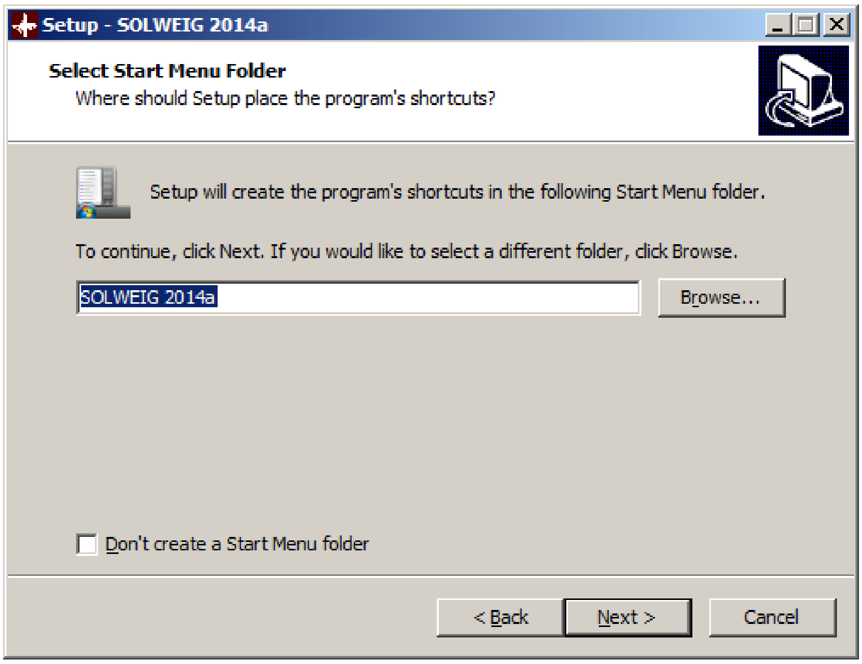

Figure 4. Select start menu folder.

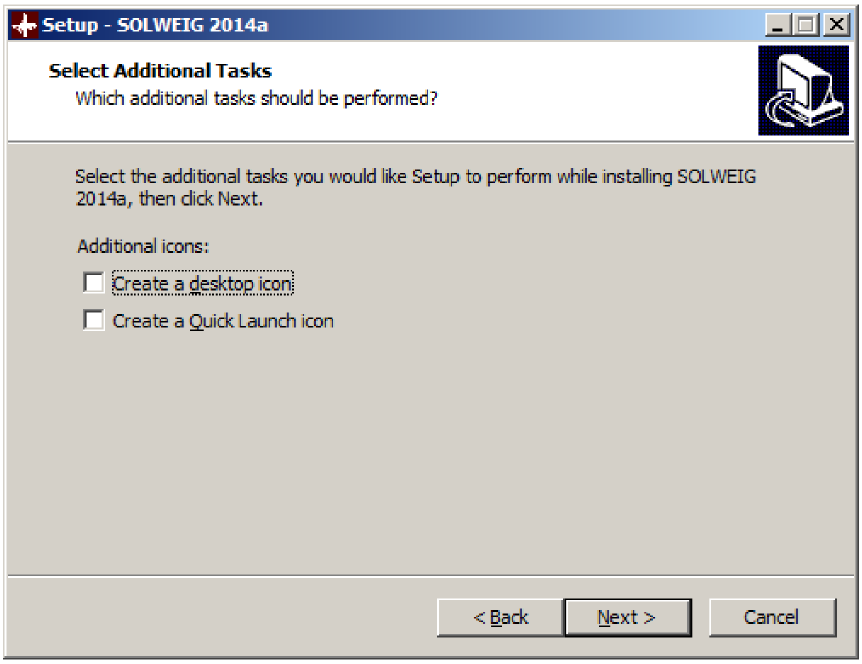

Figure 5. Create a desktop icon.

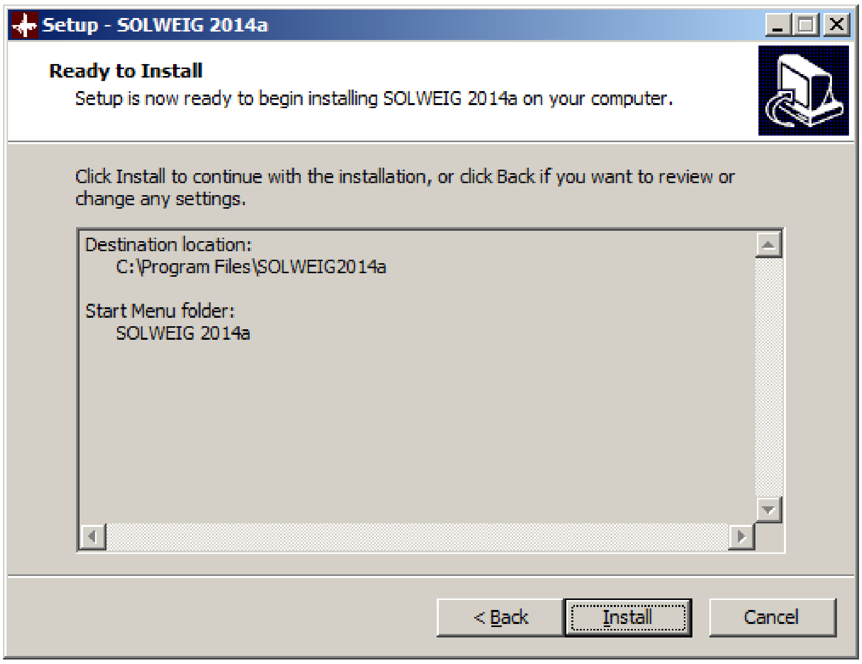

Figure 6. Ready to install SOLWEIG on your computer.

The graphical user-friendly Interface for SOLWEIG

This section explains in detail all the steps that have to be taken in order to run the SOLWEIG model by using the Interface. For each step of the model, some screenshots will be shown along with descriptions explaining the step's functionality and data that should be used and loaded.

Starting the Interface

The time it takes for the interface to actually start is relatively long compared to its size (3Mb). This is because the MCR is also initialized, which is a considerable larger application than the Interface itself.

Main frame

Figure 7 shows the initial window (or main frame) that will be displayed every time the application is launched:

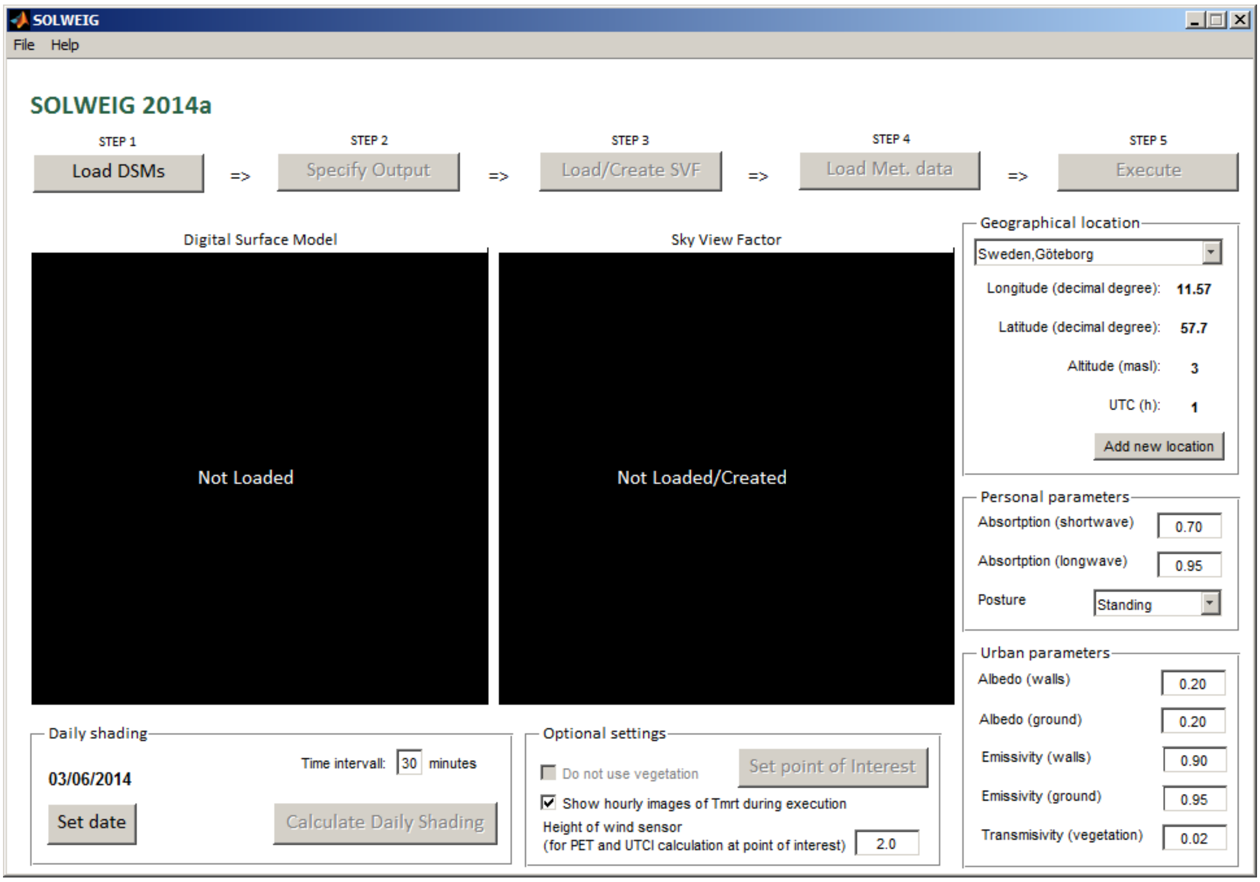

Figure 7. Main frame at the beginning

As it can be seen in Figure 7, the different steps of the model are shown in the shape of buttons at the top of the interface. The flowchart has five steps, starting from the “Load DSMs” step and ending with the “Execute”-one. Regarding the buttons in the flowchart, in the beginning there is only one which is allowed to be clicked. This indicates the starting point for running the model. After loading the first required files (those corresponding to the step one – “Load DSMs”), step button number 2 “Specify Output”, will be able to be used and so forth.

The Interface will continue enabling the remaining steps (buttons) of the model when the corresponding and required input data is loaded on the active step

STEP 1 - Load DSMs

When a button from the main frame is clicked, a new dialog pops up with all the functionality and input data related to that step of the model. In Figure 8 the “Load DSMs” step is shown in a new dialog.

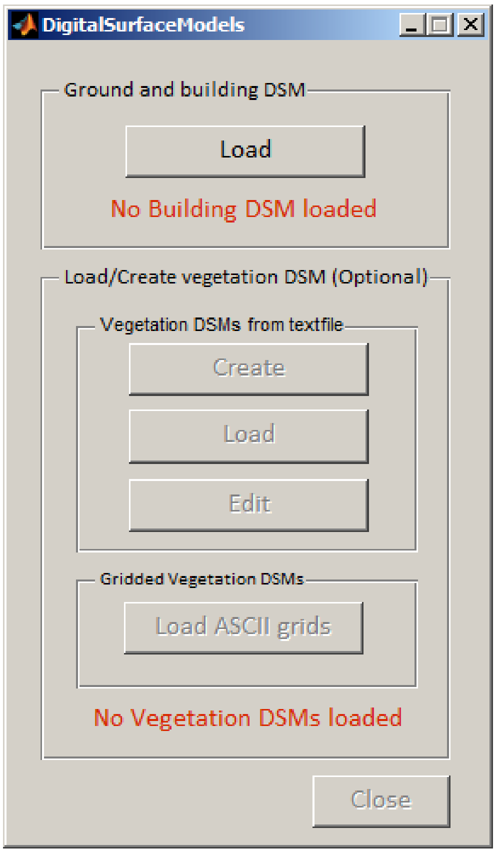

Figure 8. Load DEMs step at the beginning

Figure 8 shows how the Interface specifies the action that has to be performed in order to load the input data correctly. A raster DSM is essential for the SOLWEIG model to work and it could consist of both ground and building heights, but also of only building structures with ground elevation equals to zero. A raster DSM could be created in almost any GIS software's. A brief guide on how to create a DSM in ArcGIS can be found at the Urban Climate Group webpage. By default, the Interface will allow all types of file extensions in where a building DEM can be stored. In order for the DEM to be successfully loaded, it has to follow the **ERSI ASCII Grid** format (including the order of the headers):

ncols?#	*(# = a float number greater than zero = number of columns of the matrix)*
nrows?#	*(# = a float number greater than zero = number of rows of the matrix)*
xllcorner or xllcenter?#	*(# = a positive or negative decimal number = geographic "x" coordinate of the lower corner of the matrix). Can be either xllcorner or xllcenter.*
yllcorner or yllcenter?#	*(# = a positive or negative decimal number = geographic "y" coordinate of the left side of the matrix). Must be yllcorner when using xllcorner and yllcenter when using xllcenter.*
cellsize?#	*(# = a positive decimal number, from 0 = size of 1 pixel)*
NODATA_value?#	*(# = a positive or negative decimal number = the value of no data)*

The matrix of positive and/or negative decimal numbers representing the DEM.
Each row is separated by a new line and each column by a blank character.

The size is the one specified in the "ncols" and "nrows" headers.

Note: *(? = 1 or more blank characters, including tabs).*

An example of the above building DEM format is shown below:

ncols 350
nrows 350
xllcorner 39250
yllcorner 27993
cellsize 1
NODATA_value -9999
0.723 0.207 0.341 0.408 0.439 0.455 0.463 0.461 0.445 0.409 0.371 0.36 0.347
0.337 0.319 0.312 0.312 0.301 0.297 0.294 0.289 0.285 0.276 0.275 0.268 0.257
0.244 0.199 0.924 0.924 0.923 0.928 0.924 0.931 0.931 0.934 0.935 0.937 0.939

After loading the corresponding data, the Interface enables the other buttons in Figure 8. Since SOLWEIG version 2.0, a vegetation scheme is included. Vegetation will be represented as an additional DSM consisting of trees and bushes. Generation of vegetation units will be executed in a number of steps presented below. First, all buildings have to be identified. By clicking the "Create" button in the "Load/Create vegetation DSM (Optional)", two new figures are displayed (Figure 9). Here the user can mark the buildings within the model domain.

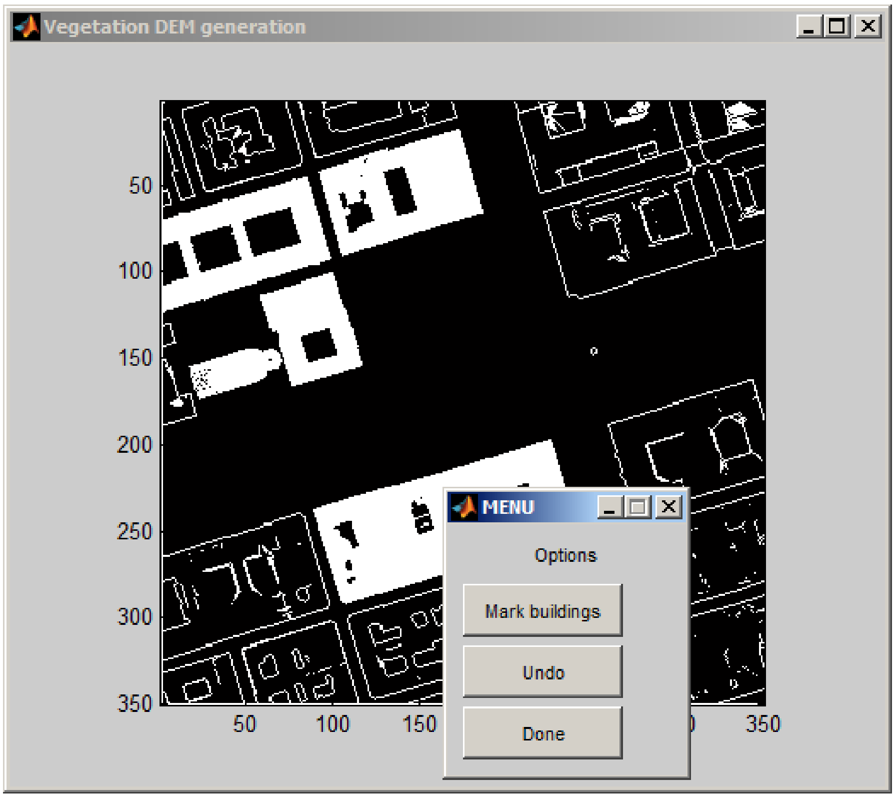

Figure 9. Load DSMs step when marking the buildings

All edges greater than 2 meter will be marked as a building wall pixel. Locations of buildings are also used even if when no vegetation DSM is used. Hence, it is suggested to go through the first step in the generation of a vegetation DSM process as shown below.

Figure 10 shows the dialog, which represent a third-level dialog where the vegetation DSM can be generated. First, one of the three standard vegetation shapes has to be selected: conifer, deciduous or bush. The Interface will then generate a vegetation unit based on the measures inserted (diameter, tree height and trunk height). Finally, the vegetation unit has to be located somewhere within the model domain. This procedure can be repeated or a vegetation unit can also be removed.

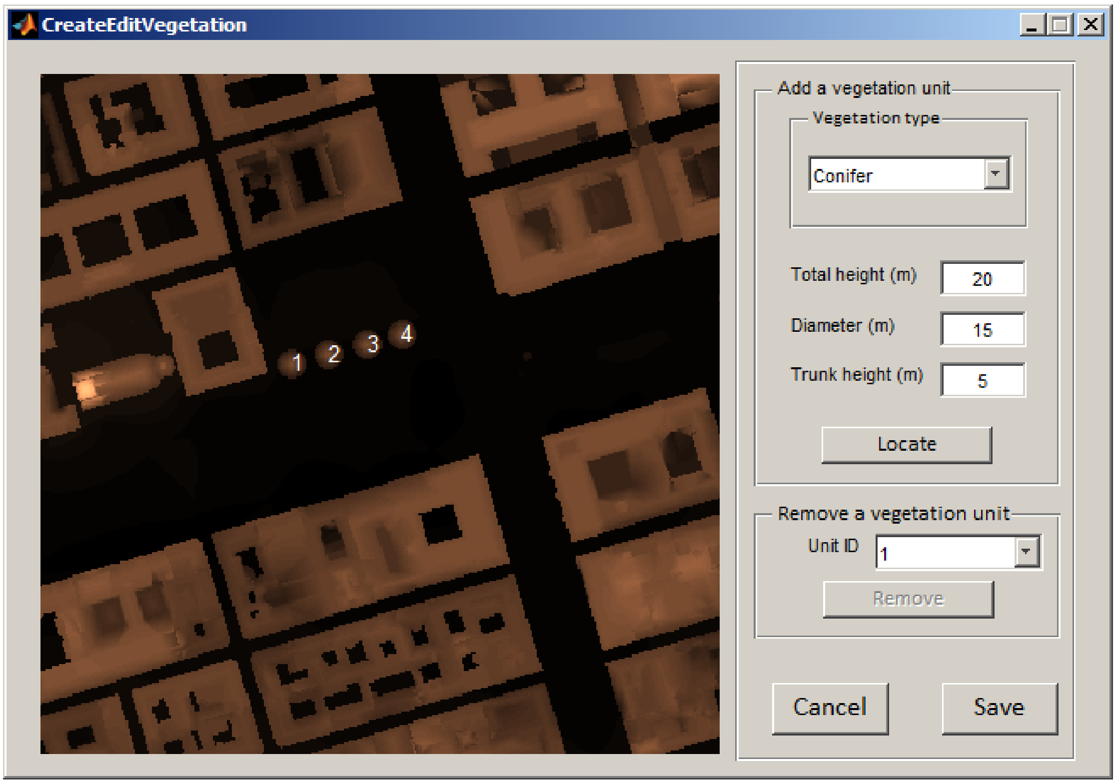

Figure 10. Load DSMs step when setting the vegetation units

By default, the Interface will allow all types of file extensions in where a vegetation DSM can be stored. In order to be successfully loaded, it has to follow the following format (including the order of the headers):

ID	*ttype*	*dia*	*height*	*trunk*	*x*	*y*	*build*
i	*t*	*d*	*h*	*tr*	*x*	*y*	*b*

Where all the columns are separated by a tab or space and:

- *i = tree identifier (a round number from 1 to infinity).*
- *t = tree type (a round number that can only have the three following values: 1 = Conifer; 2 = Deciduous; 3 = Bush).*
- *d = tree diameter in meters (a decimal number from 0 to infinity).*
- *h = tree height in meters (a decimal number from 0 to infinity).*
- *tr = tree trunk size in meters (a decimal number from 0 to infinity). This value cannot be equal or greater than the tree height. Besides, the bush tree will always have a value of 0.0 for this column.*
- *x = 'x' coordinate from the building DSM where the tree is located (a round number from 1 to the maximum 'x' value of the building DSM).*
- *y = 'y' coordinate from the building DSM where the tree is located (a round number from 1 to the maximum 'y' value of the building DSM).*
- *b = an area that corresponds with a marked building from the building DSM. This value is automatically assigned by the application the first time the user marks the buildings. Therefore if new trees are added manually, this value has to be 0.0 (decimal format). On the contrary, if there are marked buildings but not trees, there will be entries with values 0.0 in all the columns excepting in the "build" one.*

An example of the above vegetation DSM format is shown below:

ID	*ttype*	*dia*	*height*	*trunk*	*x*	*y*	*build*
0.0	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*16873.0*
2.0	*1.0*	*10.0*	*30.0*	*5.0*	*128.0*	*133.0*	*17307.0*
3.0	*3.0*	*5.0*	*5.0*	*0.0*	*182.0*	*58.0*	*10155.0*
4.0	*2.0*	*15.0*	*20.0*	*5.0*	*133.0*	*40.0*	*23081.0*
5.0	*1.0*	*5.0*	*6.0*	*5.0*	*144.0*	*234.0*	*19425.0*

Important: every time a new vegetation file is saved (or loaded) within the interface, new vegetation SVFs must be created (or loaded) as well (see below).

As shown in Figure 8, it is also possible to load and edit an already created vegetation DSM. Recently, 3D vegetation data derived from e.g. LiDAR technology has become available. Therefore, as from version 2013a, it is also possible to load already gridded vegetation DSMs into the interface. The grid should be of the same spatial resolution and extent as the ground and building DSM. The dialog shown when a gridded vegetation dataset should be used is shown in Figure 11. In order to generate realistic shadow patterns from vegetation a trunk zone DSM (specifying the volume between the vegetation canopy and the ground) is also needed (Lindberg and Grimmond, 2011). This can be loaded directly is available or be generated based on a constant value or the assumption the trunk zone is proportional to the total height of the vegetation in each specific pixel.

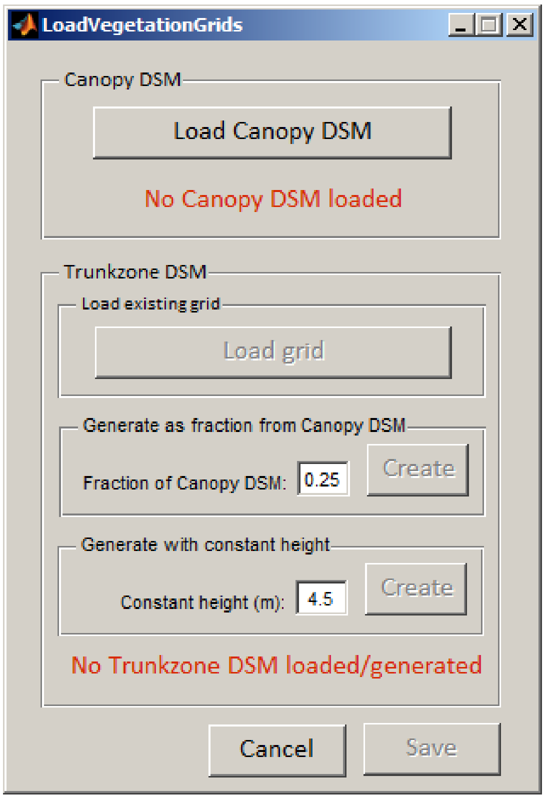

Figure 11. Dialog for loading gridded vegetation datasets.

STEP 2 - Specify Output

Options to save a number of different grids at different temporal resolution is included, both as tiff or ASCII grids. An output folder needs to be specified in order to proceed to step 3.

STEP 3 - Load/Create SVF

The Interface can also be used to obtain images of sky view factor values. Figure 12 shows the dialog that is popped up when the "Load/Create SVFs" button is clicked in the main frame. This is the most time consuming part of the model execution. The output of the SVF images generated is again as ESRI ASCII Grids. If only a ground and building DSM is loaded, vegetation SVFs is not needed.

This step allows loading of existing SVFs or creating them if they do not exist. For the case of creating the building SVFs, there are five SVFs images created for each SVF generation, one default and one for each four cardinal points per DSM. If vegetation data is used (vegetation SVF option), ten more SVF images are generated, having a total amount of ten images. They are all saved in the same zip-file that has to be specified before creating the images.

In Figure 12, the input data is already loaded; thus, by clicking on “Close” button (bottom right) the dialog will be hidden and the Interface will go back to the main frame, which now will have enabled the step buttons number four of the flowchart.

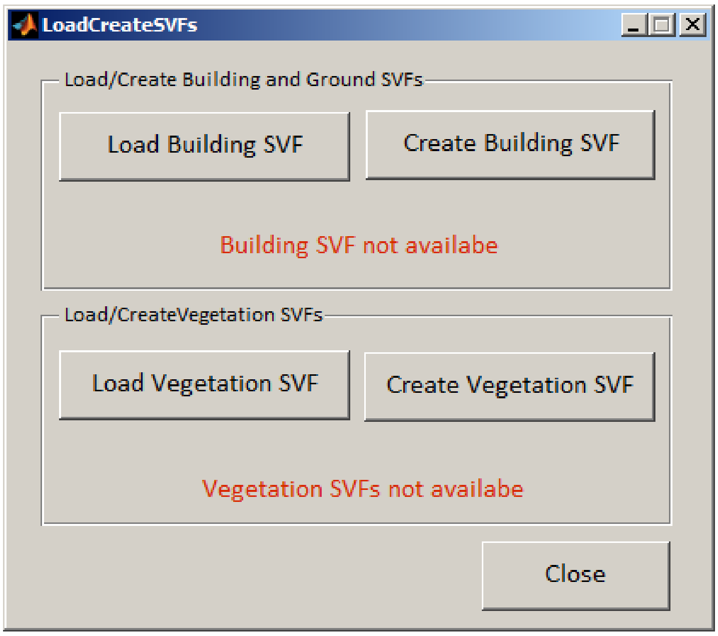

Figure 12. Load-Create SVFs when both SVFs are loaded

Figure 13 shown the main frame when both DSM and SVFs are loaded in the interface.

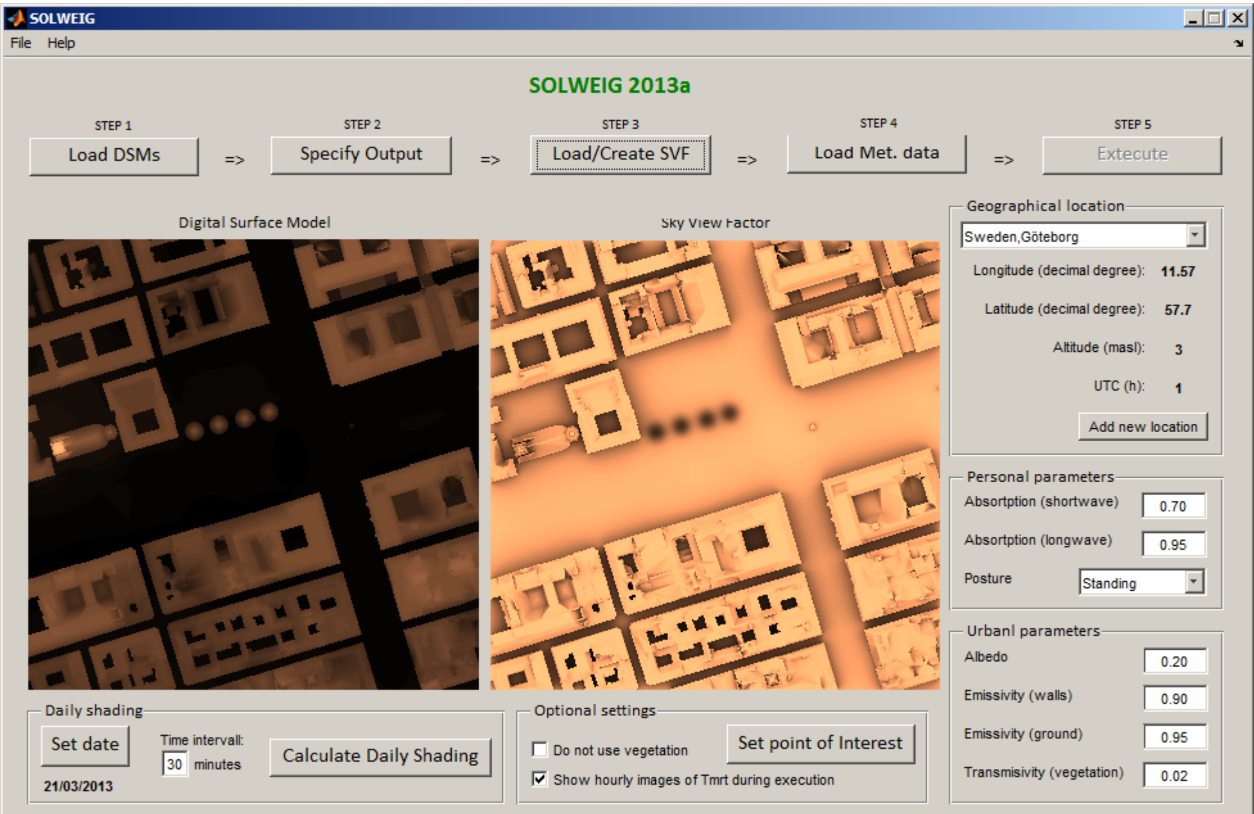

Figure 13. Load DEMs step when both DEMs are loaded

The location part (right side of the dialog) is used to locate the model domain at a geographic location on Earth. By default, the Interface provides a list of cities and their location, which can be edited or removed. Besides, new locations can be added if the desired city does not appear on the list.

STEP 4 - Load meteorological data

Figure 14 shows the dialog that is popped up when the “Load Met. data” button is clicked in the main frame.

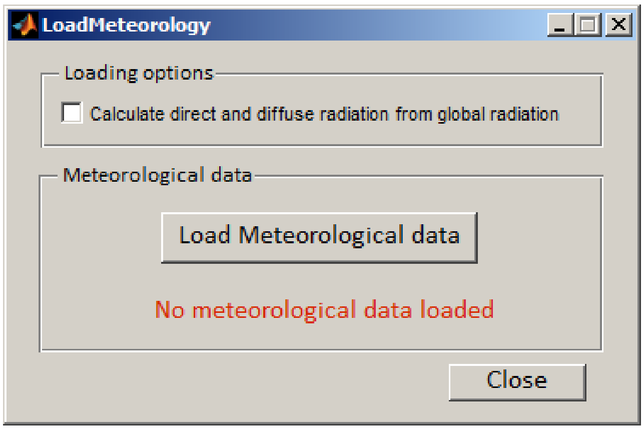

Figure 14. Add meteorological data with data loaded.

As from version 2014a SOLWEIG adopts a new format of meteorological data. This is done as SOLWEIG is planned to be incorporated in a coupled model system for climate sensitive applications. Required inputs must be continuous – i.e. gap fill any missing data. Table 1 gives the required and optional additional input variables. Variables marked with **#** in the comment column are not used with the current version and can be replaced with -999.0 if the user’s dataset does not include the variable. If a parenthesis is added the variable is optional. *Make certain these are not TAB delimited files*. By default, the Interface will allow all types of file extensions in where the meteorological data can be stored. In order to be successfully loaded, it has to follow the following format including the order of the columns.

Table 1. Meteorological input data to run SOLWEIG. Model – refers to the name within the model code.

Col	Variable	Header name	Units	Comments
1	Day of year	*id*	-	
2	Time	*it*	-	
3	Decimal time	*dectime*	-	
4	Net all-wave radiation	*qn1*	W m^{-2}	#
5	Obs. sensible heat flux	*qh*	W m^{-2}	#

6	Obs. latent heat flux	*qe*	W m^{-2}	#
7	Obs. storage heat flux	*qs*	W m^{-2}	#
8	Anthropogenic heat flux	*qf*	W m^{-2}	#
9	Mean wind speed (*U*)	*avu1*	m s^{-1}	(#)
10	Mean relative humidity	*avrh*	%	
11	Mean air temperature	*Temp_C*	°C	
12	Station air pressure	*Pres_kPa*	kPa	(#)
13	Rain	*ph*	mm t^{-1}	#
14	Incoming solar radiation	*avkdn*	W m^{-2}	
15	Snow cover fraction (0-1)	*snow*	-	#
16	Obs. downward longwave radiation	*ldown_obs*	W m^{-2}	#
17	Observed cloud faction	*fcld_obs*	Tenths	#
18	External water use	*wuh*	m^3 t^{-1}	#
19	Soil moisture	*xsmd*	m^3 m^{-3} or kg kg^{-1}	#
20	Leaf Area Index	*lai_hr*	-	#
21	Diffuse shortwave radiation	*Kdiff*	W m^{-2}	(#)
22	Direct shortwave radiation	*Kdir*	W m^{-2}	(#)
23	Wind direction	*Wd*	°	#

IMPORTANT! The direct-beam radiation (Kdir) used as input in the SOLWEIG model is **not** the direct shortwave radiation on a horizontal surface but on a surface perpendicular to the light source. Hence, the relationship between global radiation and the two separate components are:

avkdn = Kdir sin(h) + Kdiff

where *h* is the sun altitude. Since diffuse and direct components of short wave radiation is not common data, it is also possible to calculate diffuse and direct shortwave radiation by ticking the box in Figure 16 Reindl et al. (1990).

IMPORTANT! As from version 2014a, the hour time stamp is the average from the time step before, i.e. hour 3 is the time between 2 and 3 am in an hourly time resolution is used. As from version 24014a the time resolution is not set to one hour but could change based on the input meteorological data.

One additional file (ModelledYears.txt) is needed as from version 2014a. SOLWEIG can be used to model longer time periods during what the forcing data, surface cover information and different input parameters may vary. The purpose of file ModelledYears.txt is to list the years which are modelled. In this file (Table 2) the line order is important.

Table 2: ModelledYears.TXT. – in this file the line order is important.

Line	Description	Example	Comment
1	Number of years that are to be run	1	Just one year will be modelled (see section 4.1 for how to model **multiple years**)

2	Year | Start DLS | End DLS	2004 | 275 | 93	Year is 2004. **Southern hemisphere** example, the day light saving start on day of year 275 and finished on 93 (earlier in the year) For **northern hemisphere** the start and end dates would be in the middle of the year and the start date would be smaller than the end date.

In the example below "!" indicates comments in the file. Comments are not read by the programme so they can be used by the user to provide notes for their interpretation of the contents.

Example of **ModelledYears.txt** when multiple years (in this case 2008 and 2009) are run

```
2                           !Number of modelled years/time periods
2008    170    240          ! Year  --  start of Daylight Savings   -End of Daylight savings
2009    172    242
```

Note! For both years all other input files with *YYYY* are needed. The respective output files will be created. Day of Year is used in all calculations. Leap years are taken into account and will be determined for each year. In the current version of SOLWEIG (2041a), Daylight Savings is not used and could therefore be ignored. Examples of the input files is found in the '**test files**' folder.

STEP 5 - Execute

By clicking on the "Execute" button, the SOLWEIG model will be launched.

Set model parameters

There are a number of settings that can be made in the main frame of the interface. The model parameters are divided into geographical, urban and personal parameters. It is possible to use the default values or to specify new values.

Optional settings

Some optional settings are also available. If the option "Show hourly images of T_{mrt} during execution" is selected, the results will be shown. There is also an option to exclude the vegetation scheme ("Do not use vegetation").

Set point of interest

Figure 15 shows the window that pops up when the button "Set point of interest" is clicked on the main frame.

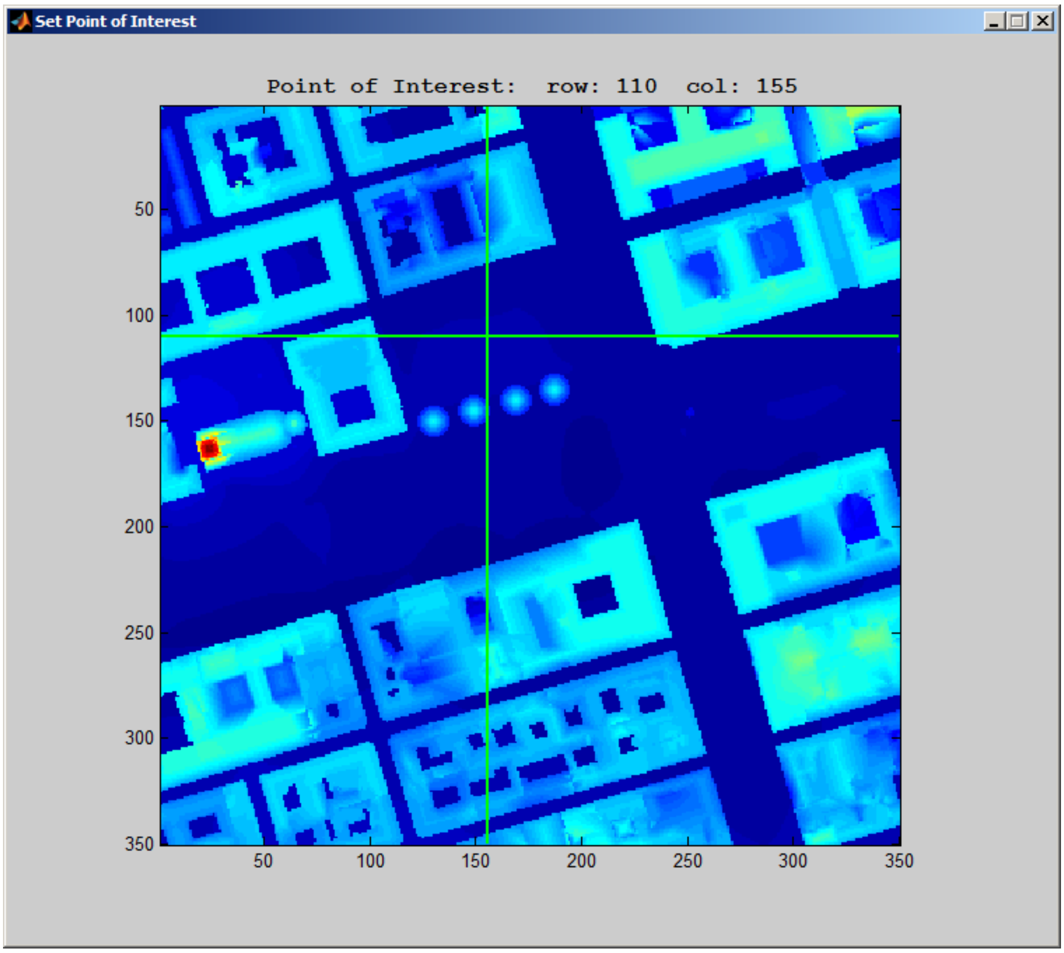

Figure 15. Set point of interest with point set

In order to specify a point of interest, the mouse cursor has to be used to point the cursor over the shown DSM and then click on the desired area within the map. For this purpose, the coordinates the cursor is pointing to in real time is shown to facilitate the point's selection. The height will be referring to the centre of gravitation of a standard male (1.1 m agl).

The point of interest is a location where more detailed information of the model can be extracted. The text-file generated includes the following attributes:

year	year
month	month of year
day	day in month
hour	hour of day
altitude	altitude of the Sun (in degrees)
azimuth	azimuth of the Sun (in degrees)
Kdirect	Direct beam solar radiation (calculated of from meteorol. data)
Kdiffuse	diffuse component of radiation (calculated of from meteorol. data)
Kglobal	global radiation (from meteorological input data)
Kdown	downward shortwave radiation
Kup	outgoing shortwave radiation
Knorth	shortwave radiation from north

Keast	shortwave radiation from east
Ksouth	shortwave radiation from west
Kwest	shortwave radiation from south
Ldown	downward longwave radiation
Lup	outgoing longwave radiation
Lnorth	longwave radiation from north
Least	longwave radiation from east
Lsouth	longwave radiation from west
Lwest	longwave radiation from west
Ta	air temperature from meteorol. Data
Tg	calculated surface temperature
RH	relative humidity from meteorol. data
Ea	vapor pressure
Esky	ky emissivity
Sstr	mean radiant flux density
Tmrt	mean radiant temperature
I0	theoretical value of maximum incoming solar radiation
CI	clearness index for L_{down} (Based on Crawford and Duchon, 1999)
Gvf	Ground View Factor
CI_Tg	clearness index used for calculating T_a/T_s differences (Based on Reindl et al. 1990)
Shadow	Shadow value
SVF_b	Sky View Factor from ground and buildings
SVF_b+v	Sky View Factor from ground, buildings and vegetation
PET	Physiological Equivalent Temperature
UTCI	Universal Thermal Climate Index

Calculate Daily Shading

A separate feature of the interface is found in the lower left corner of the main frame, namely to generate shadow patterns on for the loaded DSMs based on geographic location and day of year. It is also possible to specify the interval between each shadow map generation.

The “Calculate Daily Shading” becomes available after DSMs are loaded and an output folder is specified. No SVFs or meteorological datasets are needed. Figure 16 shows an example of the result generated using the daily shading feature.

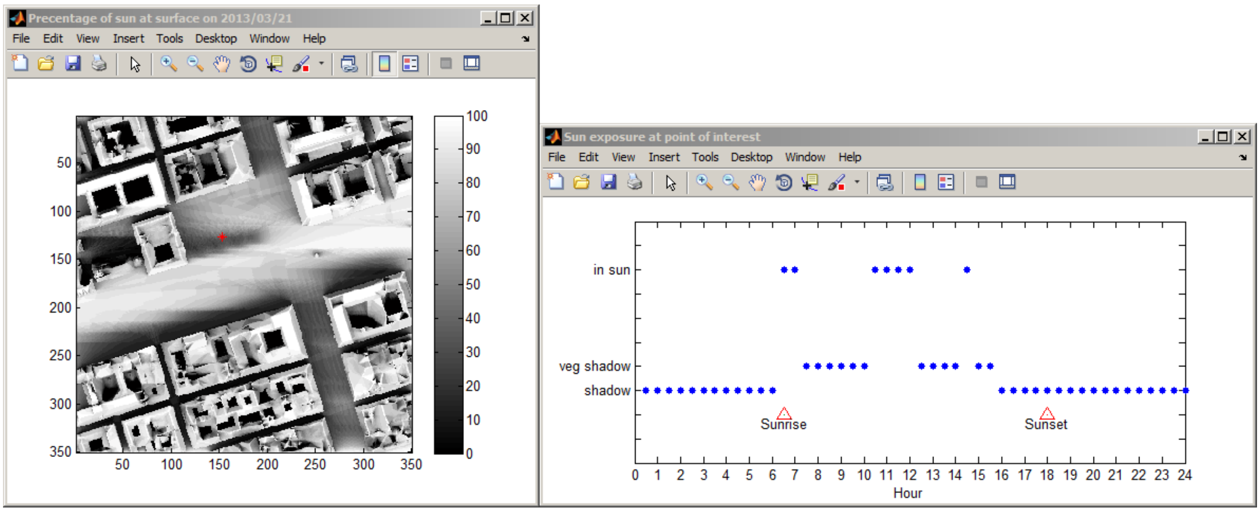

Figure 16. Example of Daily Shading results

Tips and hints

In this section, a few recommendations are presented which will help you to obtain the best result using the SOLWEIG model:

- The model makes the most accurate estimations of the radiative fluxes if the locations of the building are known. When the vegetation scheme is used the buildings is identified. However, using the model without the vegetation scheme results in an automated identification of the building footprints is used which introduce error due to the fact that courtyard also will be identified as buildings. To resolve this, create an empty vegetation DSM and then click in ”Do not use vegetation”. This makes the model use the identified buildings instead of using the automated building generation algorithm.
- Look in the “test files”-folder for examples on how the input data should look like. There you will find DSMs, meteorological data files etc.

Upcoming versions

The SOLWEIG model is in a development process and we are constantly working on refinement and improvements of the model. Our plans so far are to present these changes in one major upgrade:

Two major changes are planned in the upcoming versions. First, a land use scheme will be incorporated which gives the opportunity to change surface characteristics and separate between vegetation types more explicit. Second, possibilities to calculate PET (Physiological Equivalent Temperature) will also be included. This requires an estimate of wind speed which is currently not included in the model. The aim is still to improve the surface temperature parameterization and the temporal resolution. Furthermore, a coupling with a surface energy model and a convective boundary model is in progress. After this, it will be possible to modify the meteorological data based on surface characteristics within the model domain.

Acronyms and abbreviations

ASCII: American Standard Code for Information Interchange.

DSM: Digital Surface Model.

MCR: MATLAB Compiler Runtime.

SOLWEIG: SOlar and LongWave Environmental Irradiance Geometry.

SRS: Software Requirements Specification.

SVF: Sky View Factor.

UTC: Coordinated Universal Time.

References

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